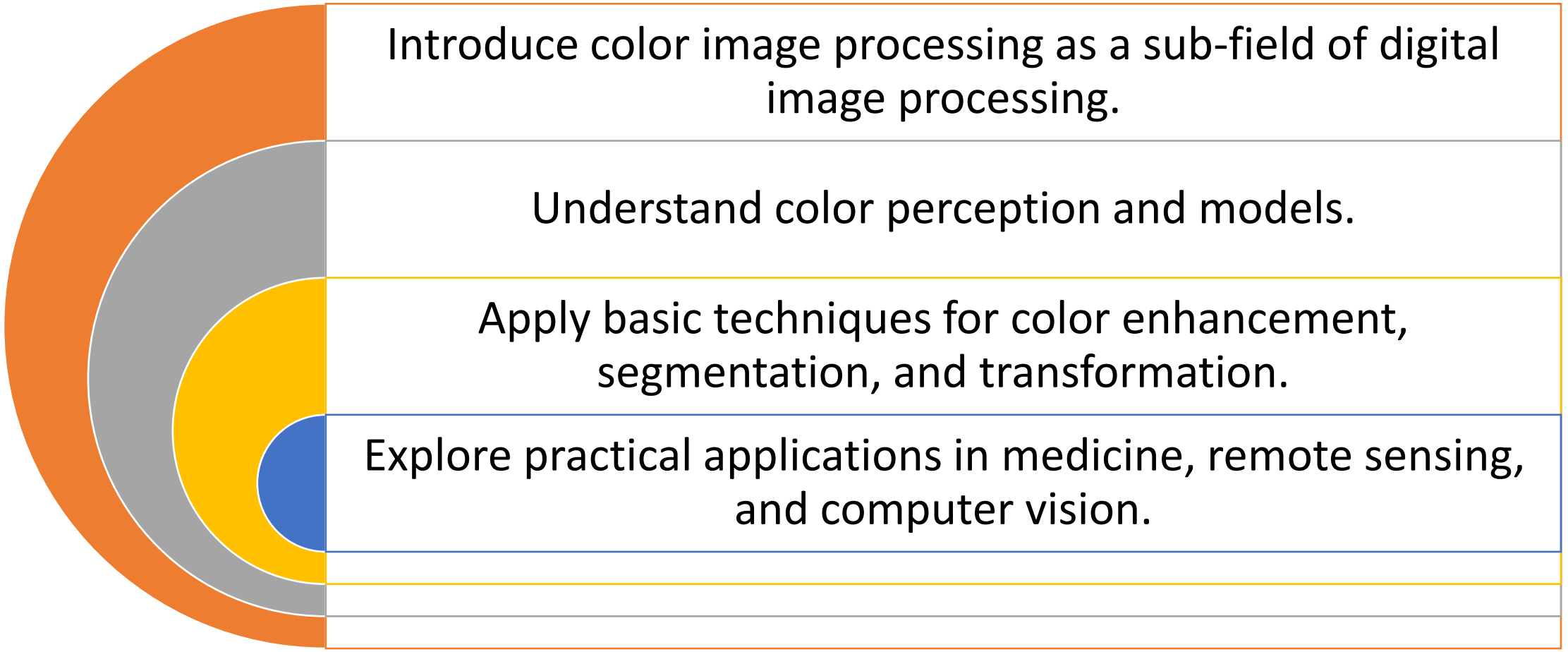
Color Image Processing

Dr. Abdul Rehman Abbasi

Learning Outcomes/Purpose


Introduce color image processing as a sub-field of digital image processing.
Understand color perception and models.
Apply basic techniques for color enhancement, segmentation, and transformation.
Explore practical applications in medicine, remote sensing, and computer vision.

Why Color?

Why Color?

Why Color?

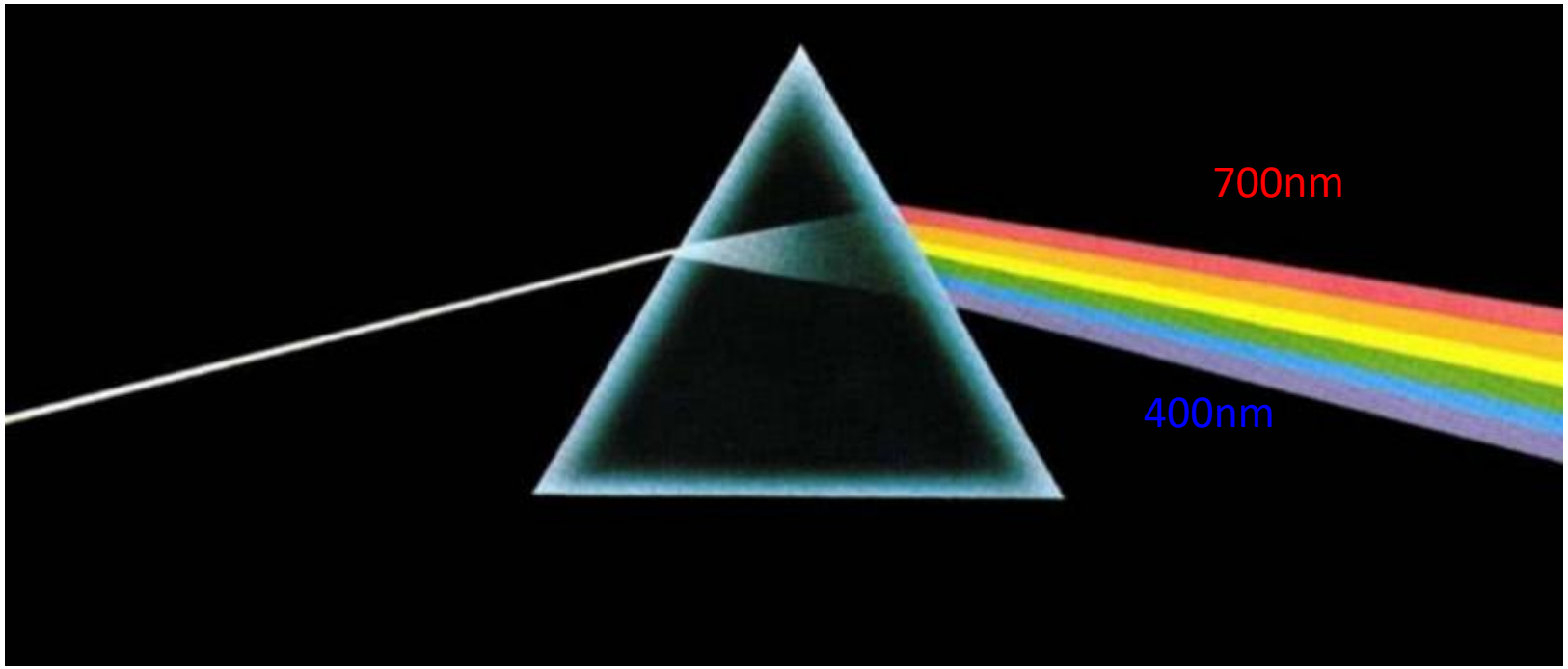
Color adds critical information for interpretation.

Improves segmentation and object recognition.

Used in surveillance, multimedia, medical imaging, and more.

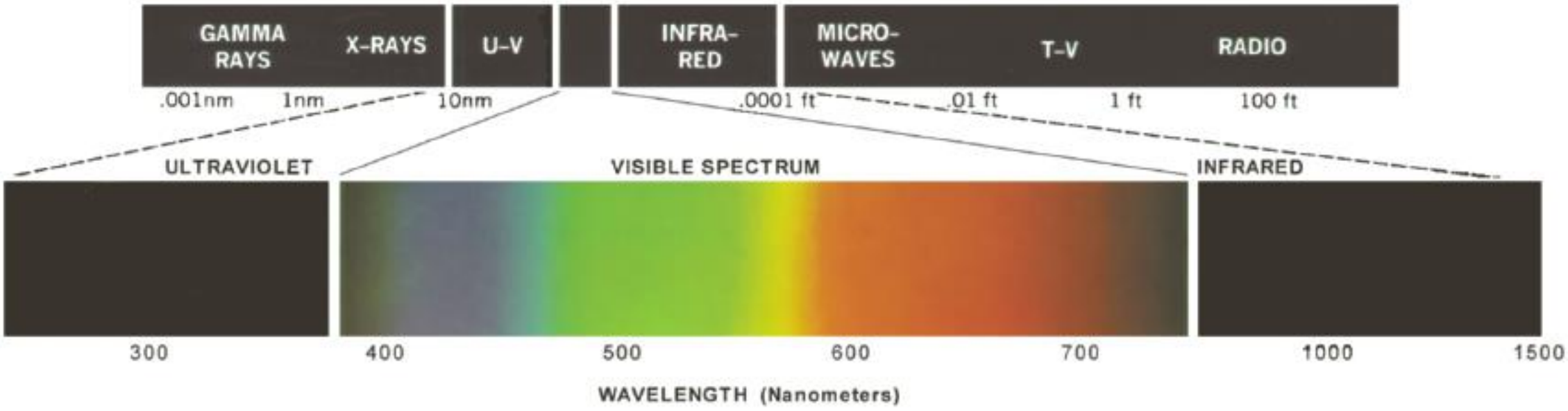
Human Vision & the Visible Spectrum

- Human eye perceives wavelengths from ~400nm to 700nm.
- Cone cells in retina detect color: L (red), M (green), S (blue).
- Color is a psychological interpretation of wavelength combinations.



Visible Light

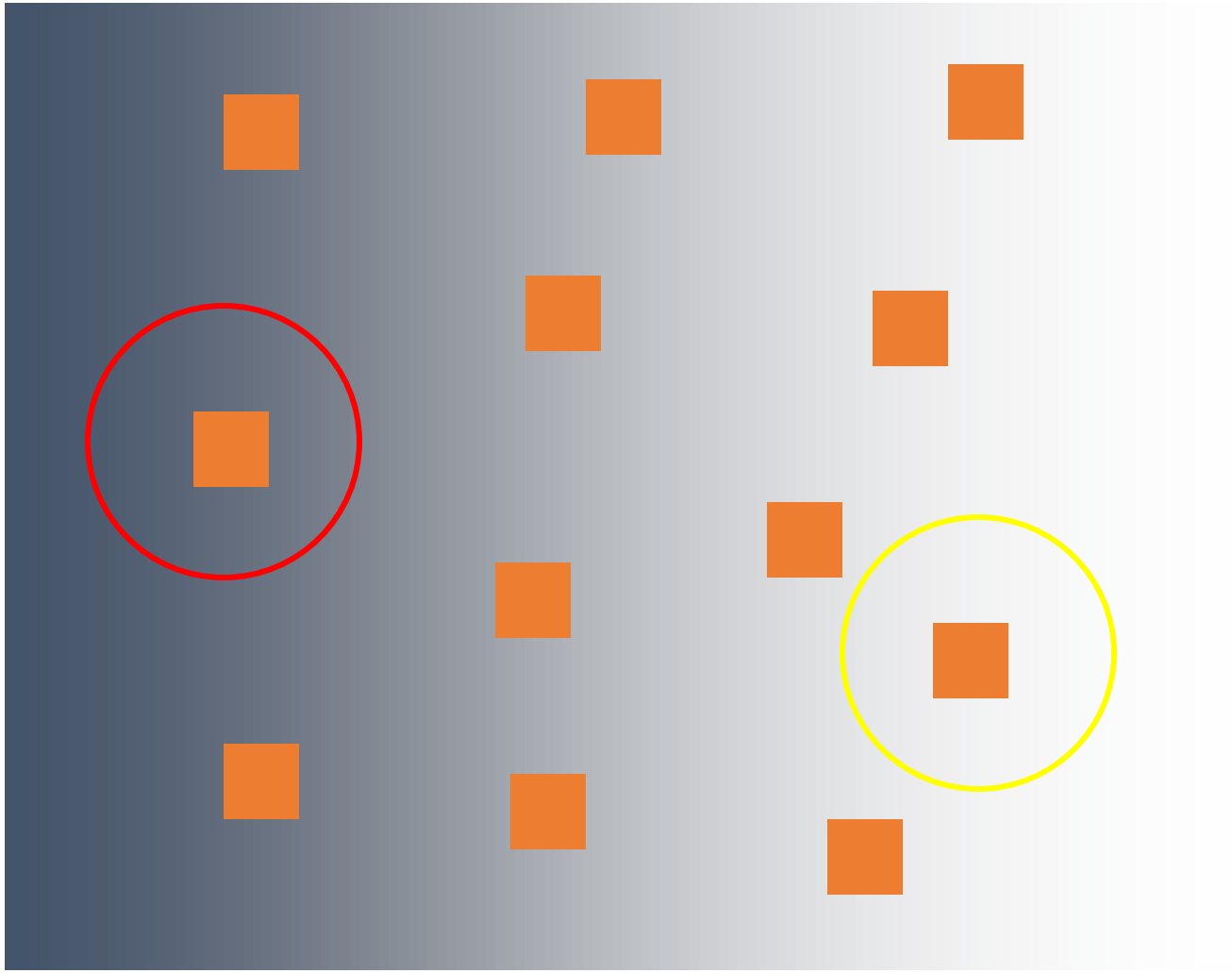
- Visible light composed of relatively narrow band of frequencies in electromagnetic spectrum
- Chromatic light spans EM spectrum from around 400 to 700 nm

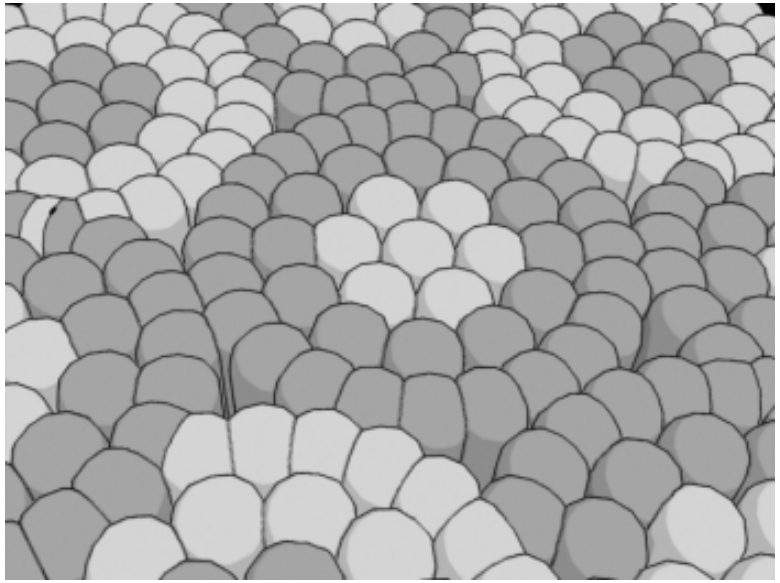


Do objects have color?

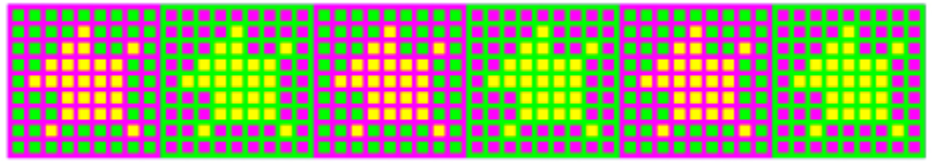
- NO - objects have pigments
- Absorb all frequencies except those which we see
- Object color depends on the illumination

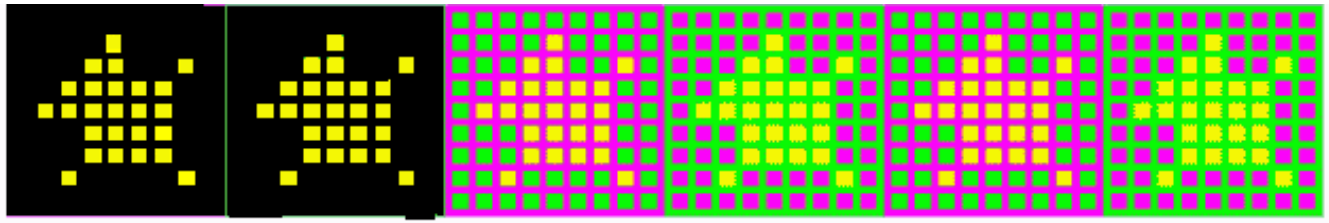
Brightness perception





Color perception





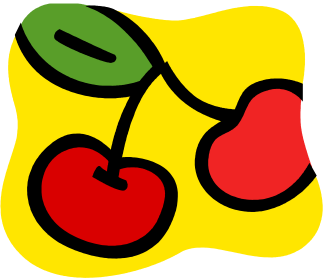
Cells in the retina combine the colors of nearby areas

Color is a perceptual property

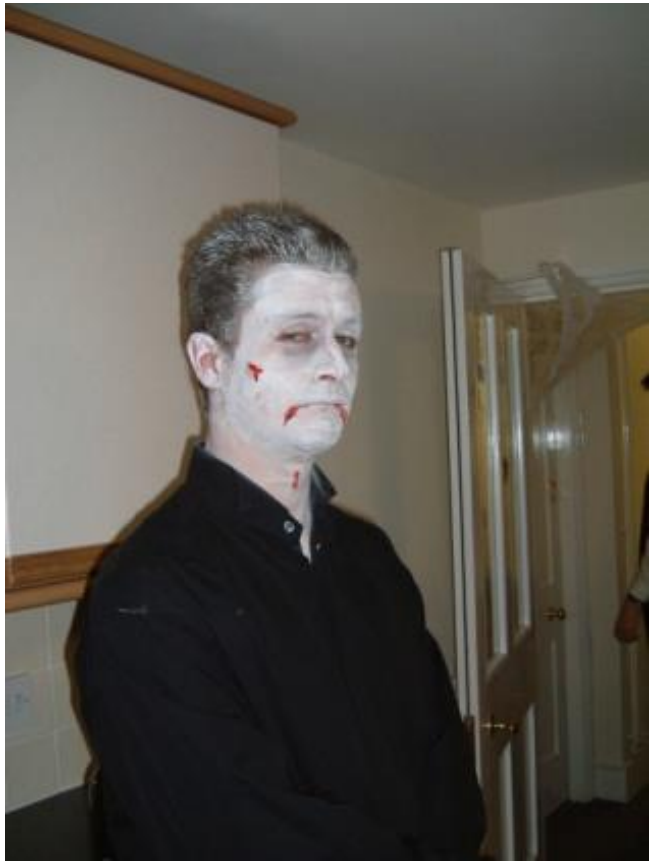
Color Perception

- Perceived color of an object based on nature of light reflected from object
- Examples:
  - If object reflects light that's balanced from all visible wavelengths, object is perceived as white
  - If object reflects light with wavelengths mainly in the 575 to 625nm range, object is perceived as red

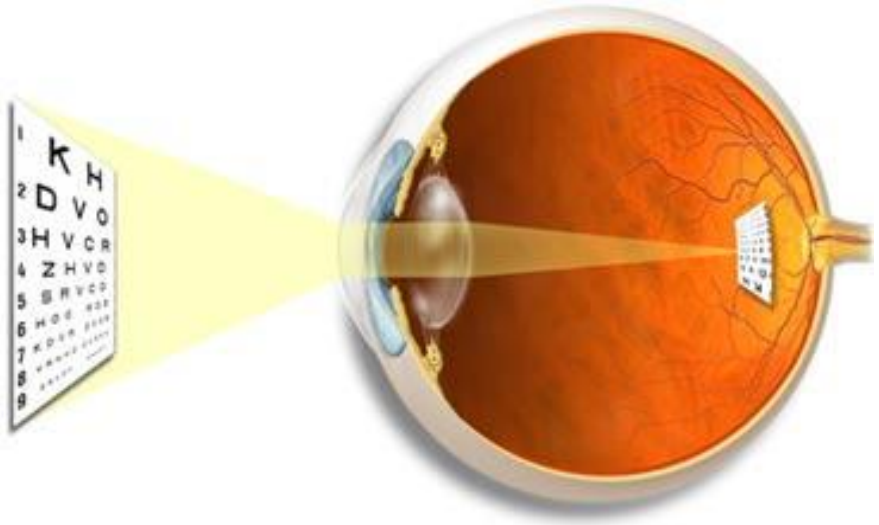
Why is Color Important?



- In animal (human) vision
  - food vs. nonfood
  - identify predators and prey
  - check health, fitness, etc. of other individuals.
- In machine vision
  - Recognition [Schiele96, Swain91]
  - Segmentation [Klinker90, Comaniciu97]



How do we sense color?



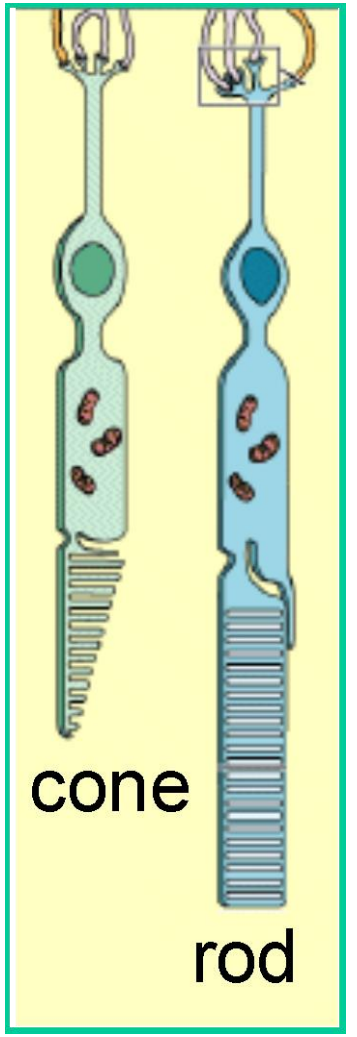
Rods

- Very sensitive to light
- But don't detect color

Cones

- Less sensitive
- Color sensitive

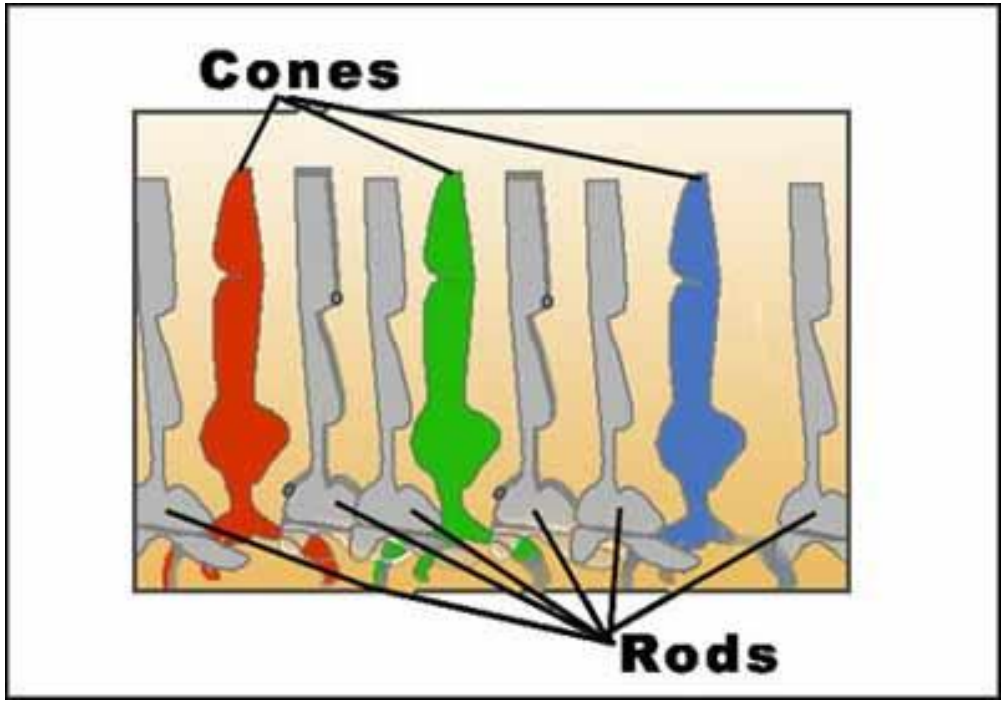
- Colors seems to fade in low light

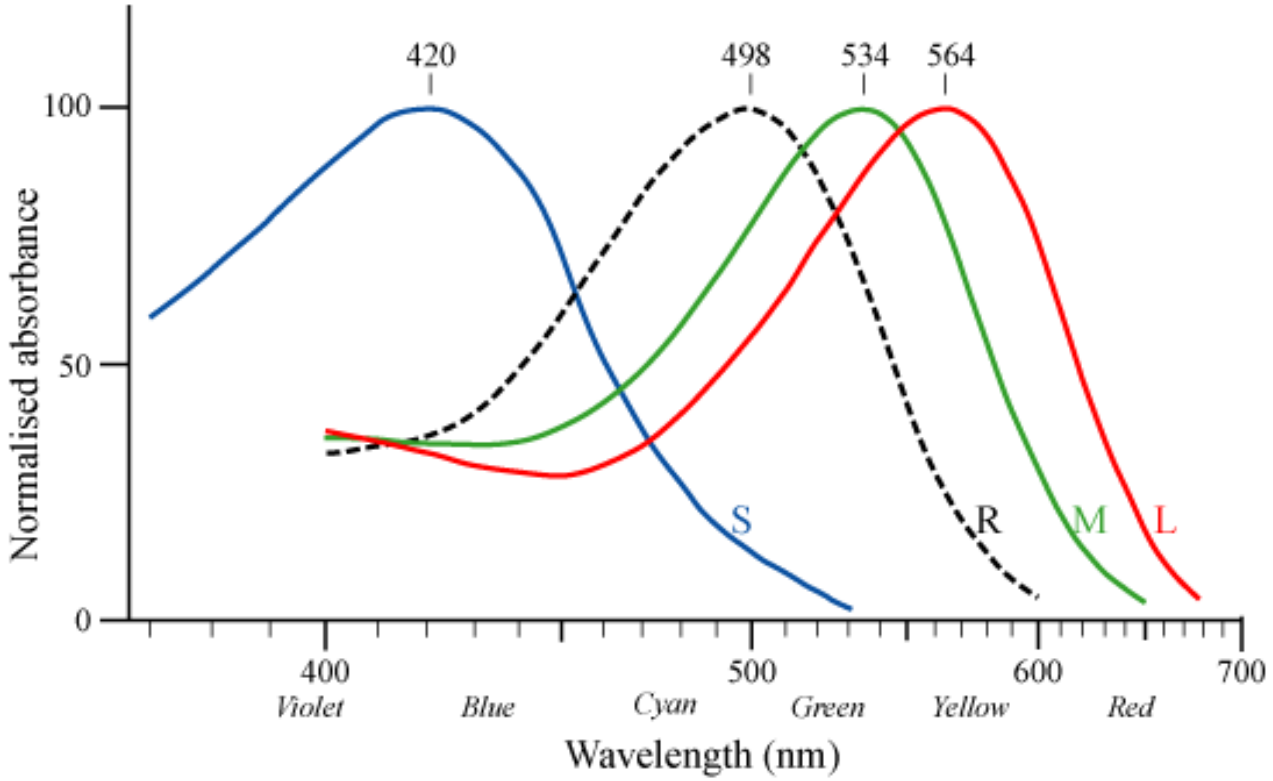


Cones Revisited

- 6 to 7 million cones in the human eye
- Divided into three main types:
  - L cones (65%)
    - Maximally sensitive to long wavelengths (e.g., red)
  - M cones (33%)
    - Maximally sensitive to medium wavelengths (e.g., green)
  - S cones (2%)
    - Maximally sensitive to short wavelengths (e.g., blue)

What Rods and Cones Detect

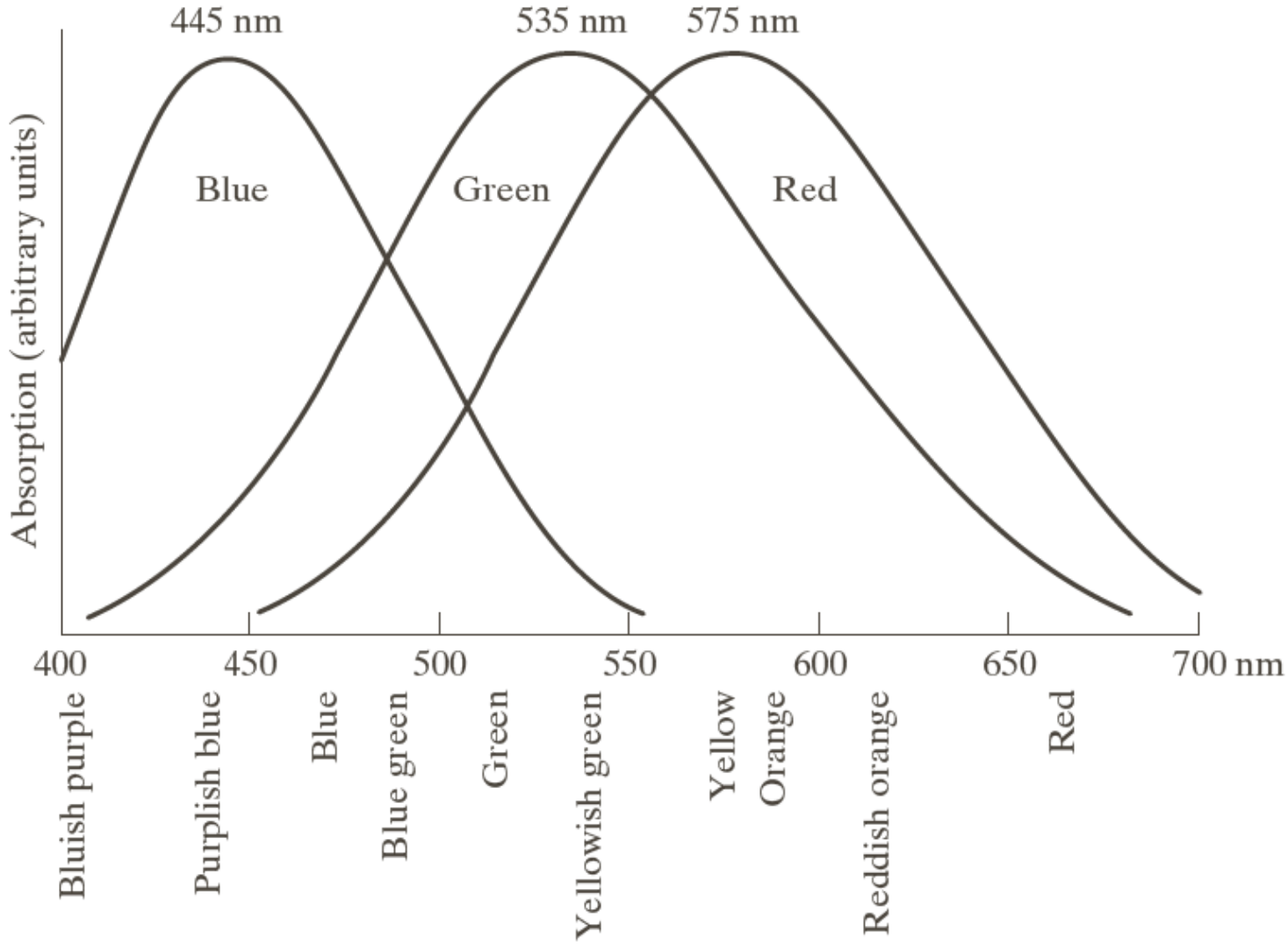




Responses of the three types of cones largely overlap

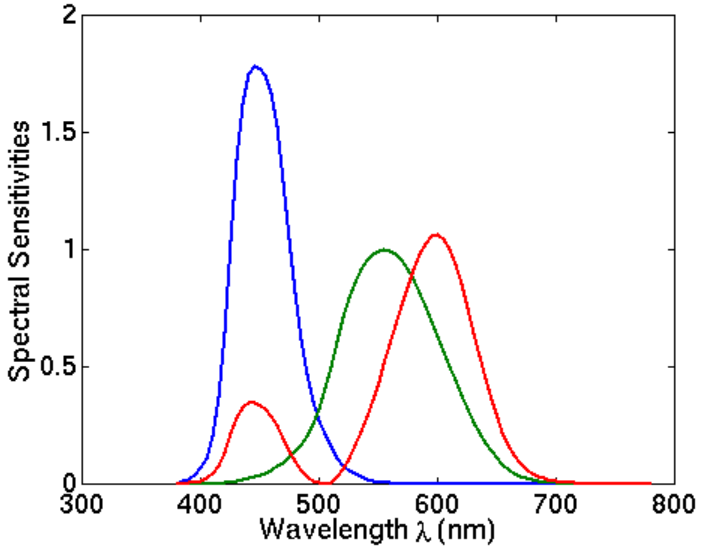
Light Absorption of Cones

- Visible colors can be visualized as weighted combination of primary colors red, green, and blue

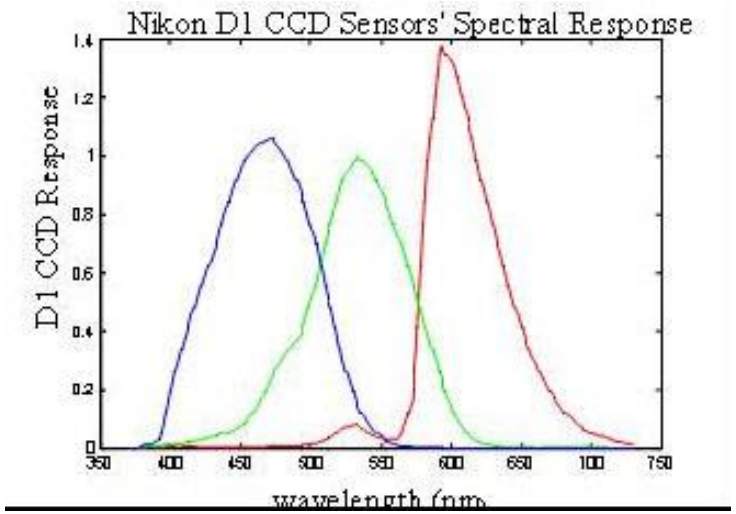


Eye / Sensor

Eye



Sensor



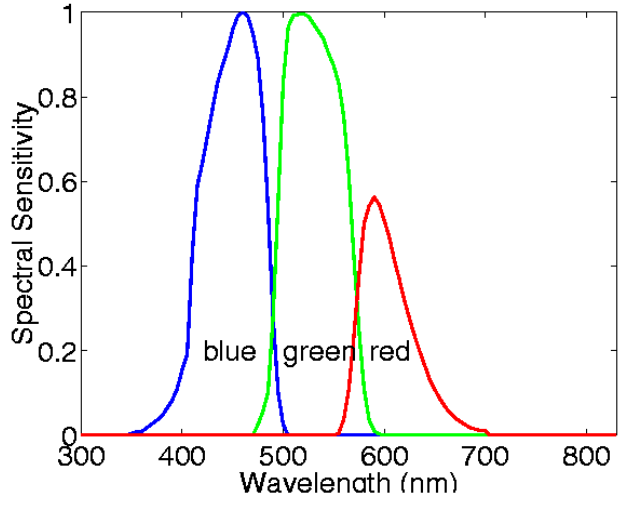


Image formation

Image color

$$E_k = \int_{\lambda} e(\lambda)s(\lambda)\rho_k(\lambda)d\lambda$$

$k = R,G,B$

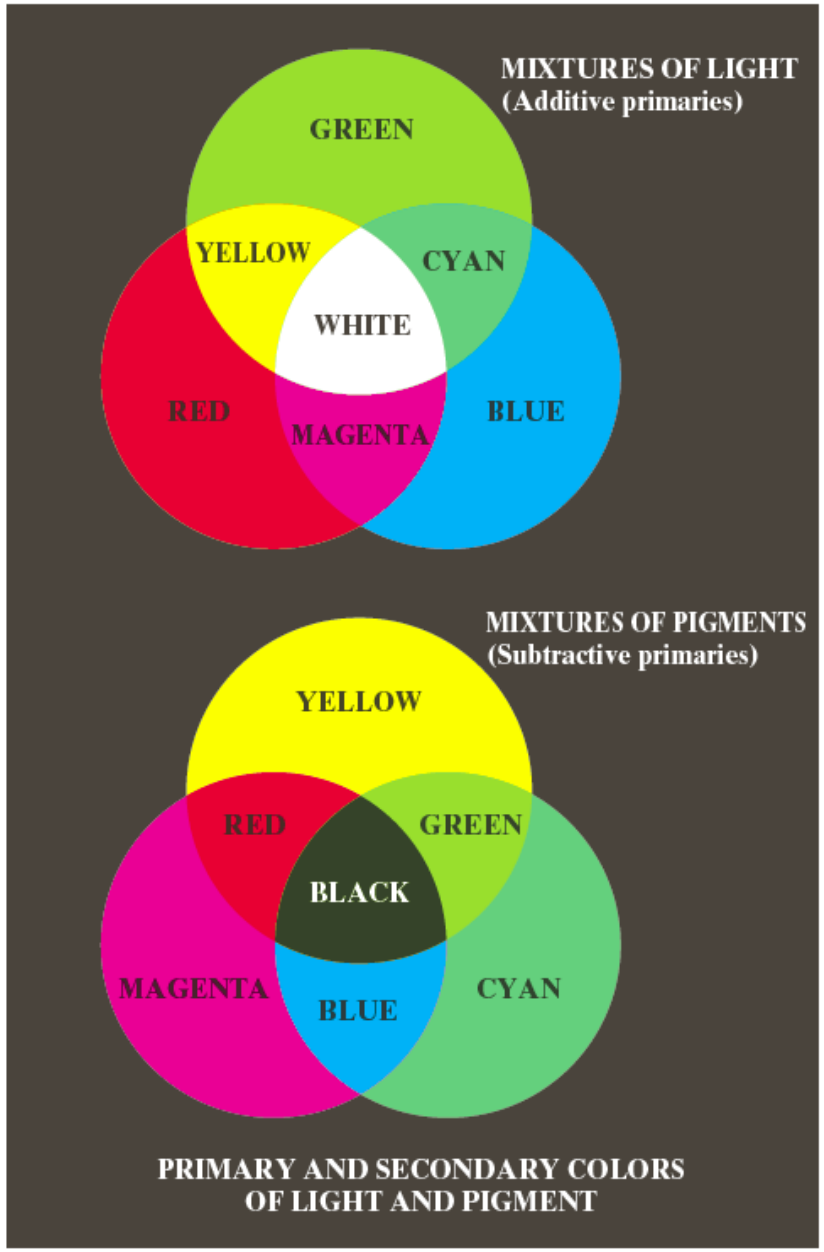
Illumination

object reflectance

Sensor response

Mixtures of Light vs. Mixtures of Pigments

- Mixture of light primaries additive
- Mixture of pigment primaries subtractive

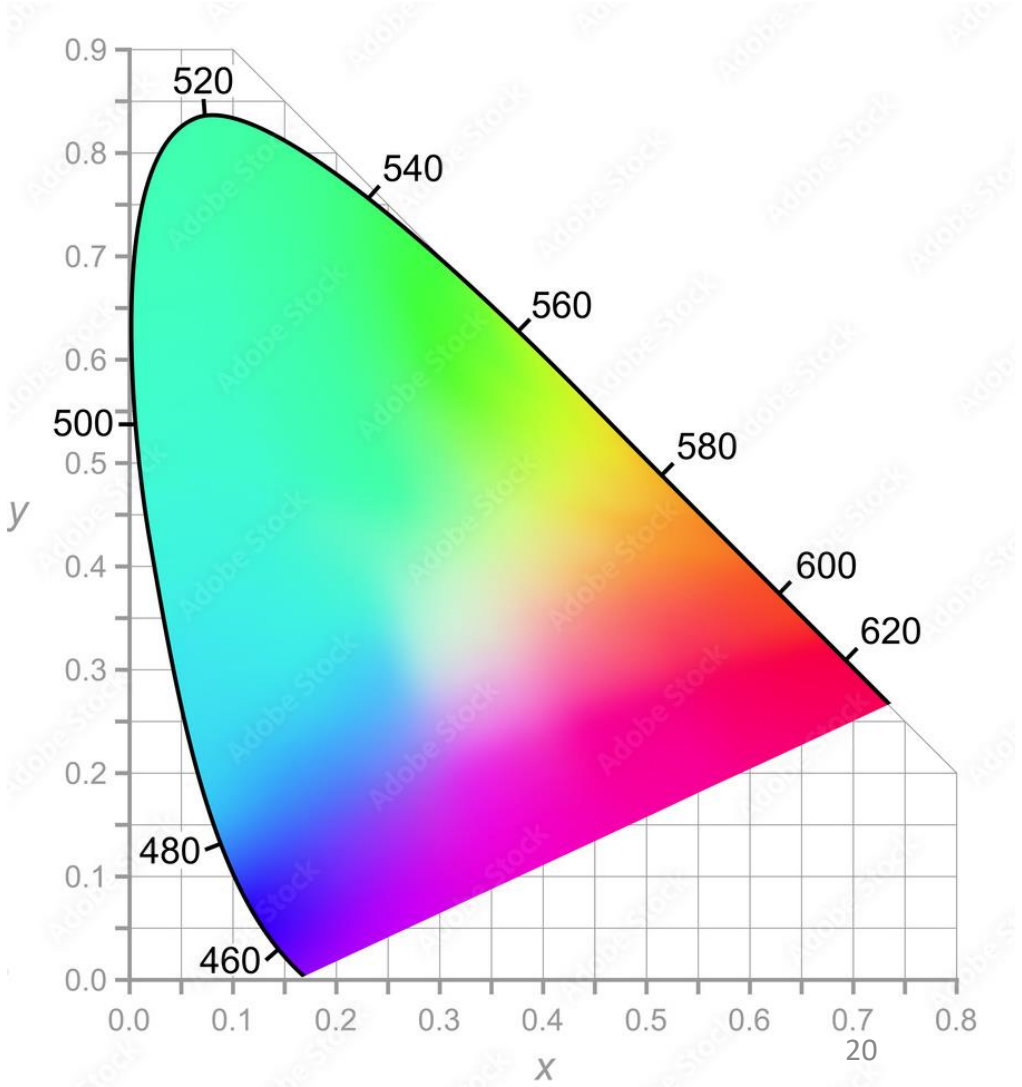


CIE Chromaticity Diagram

- A method for specifying colors
- Specifies color composition as function of *x* (red) and *y* (green)
- For any value of *x* and *y*, value of *z* (blue) can be found as

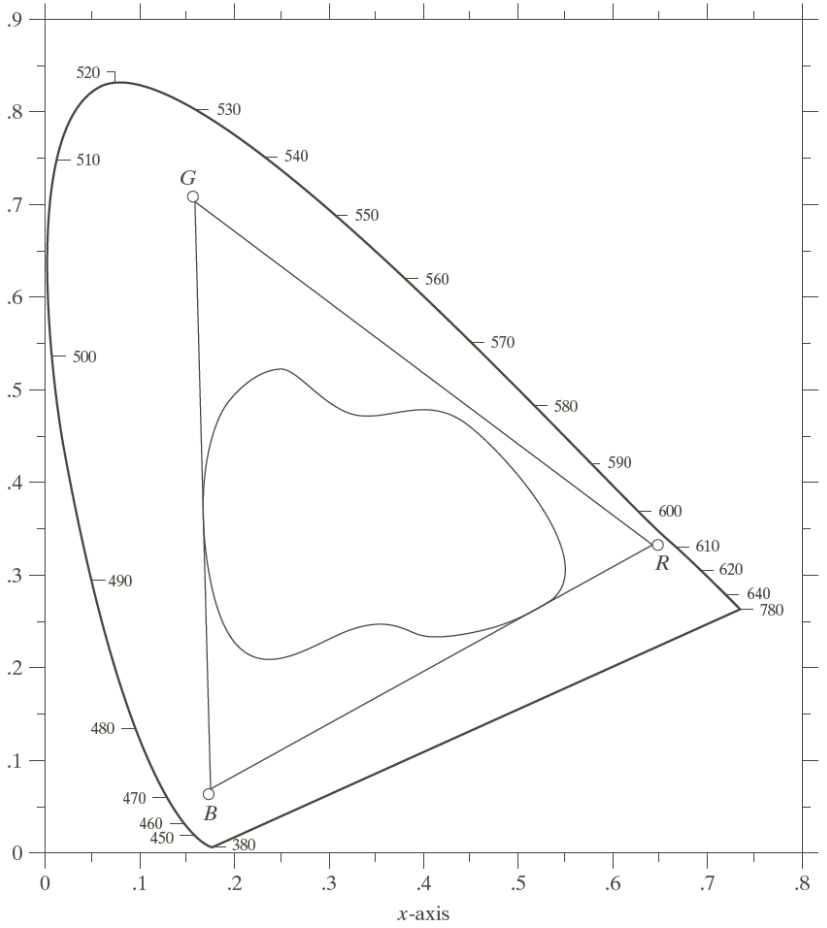
$$z = 1 - (x + y)$$

- The *(x,y,z)* values of a color specifies percentage of red, green, and blue needed to form the color (**Trichromatic Coefficients)**

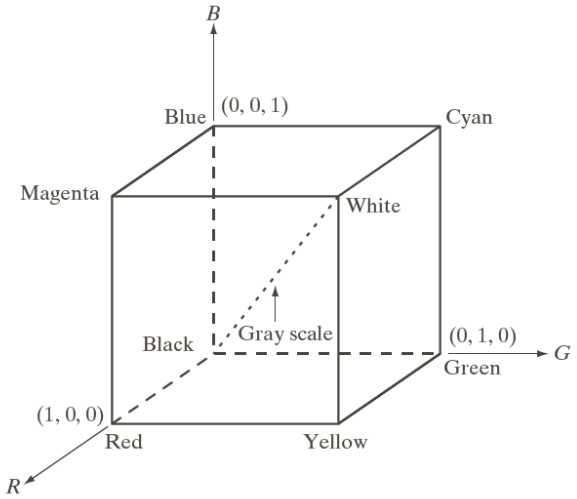


CIE Chromaticity Diagram Interpretation

- Pure spectrum colors located around boundary
- All non-boundary colors are mixture of spectrum colors
- Point of equal energy corresponds to equal fractions of the three primary colors
  - CIE standard for white light
- Straight line segment joining two points define all colors that can be created by mixing these two colors additively

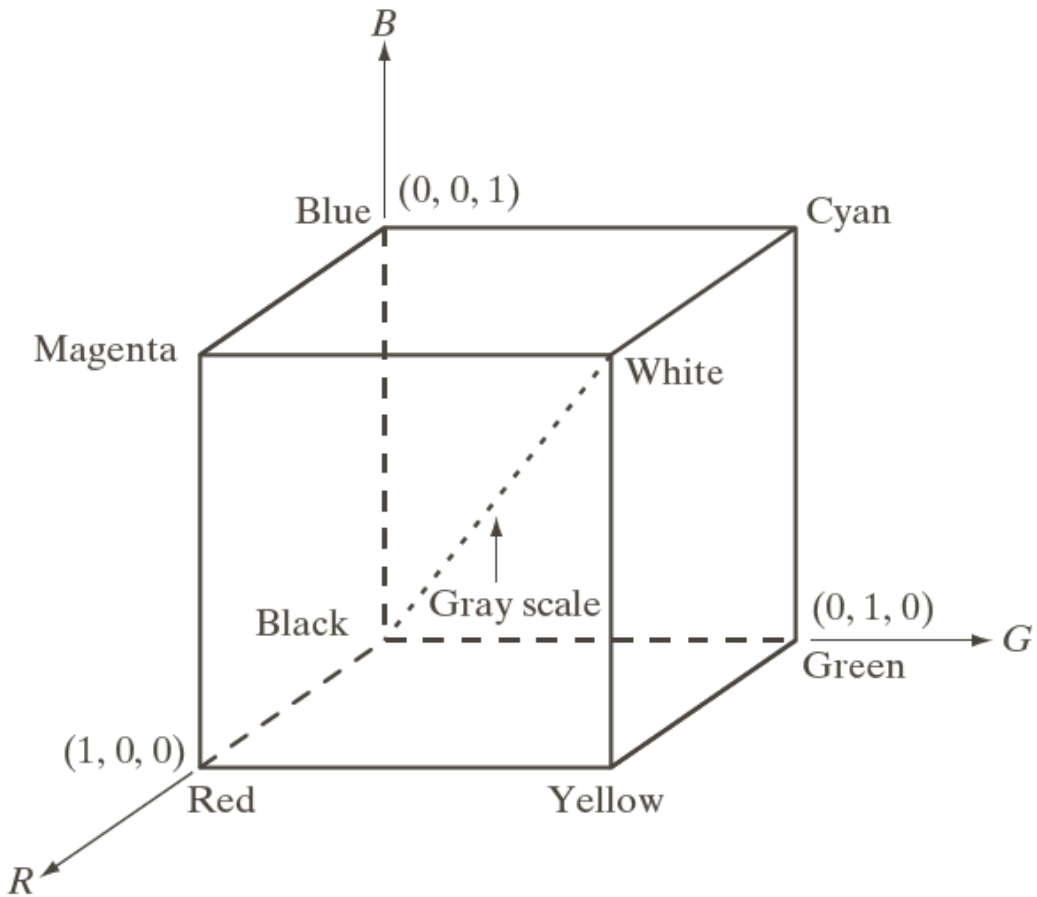


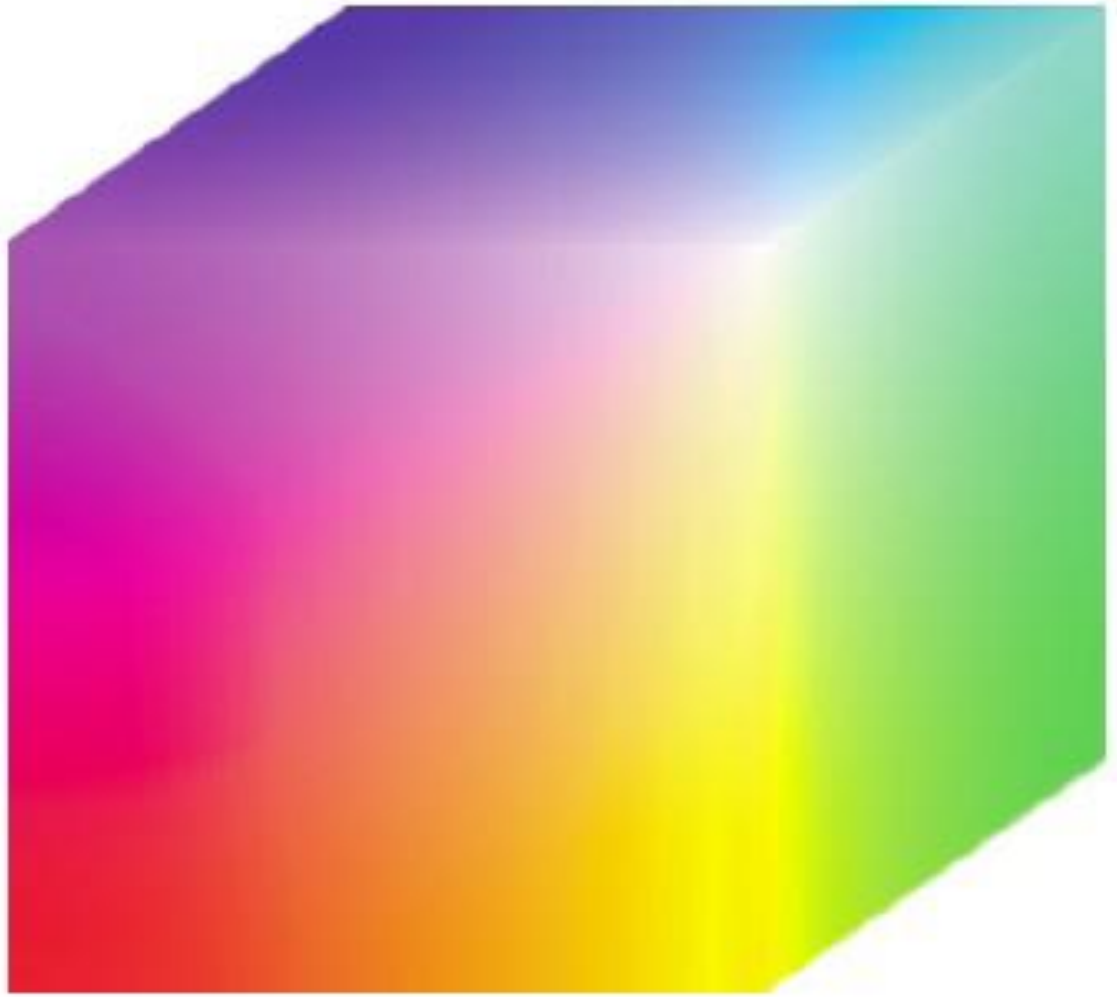
RGB Color Model



- Primarily used for displays and cameras
- Based on Cartesian coordinate system
- Three axis represents intensities of red, green, and blue
- Gray scale (points of equal RGB values) extends from black (0,0,0) to white (1,1,1)
- Example: 24-bit color (Truecolor)
  - 8-bits (256 levels) are used to represent each channel
  - Gives a total of $(256)^3$=16,777,216 possible colors!

RGB Color Model Visualization





Additive & Subtractive Color Space

Additive (RGB):

- Used in displays, light sources.

Subtractive (CMY):

- Used in printing, pigments.

CMY/CMYK Color Models

- Primarily used for printing
- Based on primary colors of pigments
- For CMY, the three axis represent the amount of cyan, magenta, and yellow pigments to put in to produce a certain color

Why K?

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Why K?

- In theory, equal amounts of cyan, magenta, and yellow produces black
- In practice, combining them results in muddy-looking black
- To produce true black in printing, a fourth color (black) is added to produce the CYMK color model

Pros and Cons of RGB

Advantages of RGB model

- Straightforward (great for hardware implementation)
- Matches well with human vision system's strong response to red, green, and blue

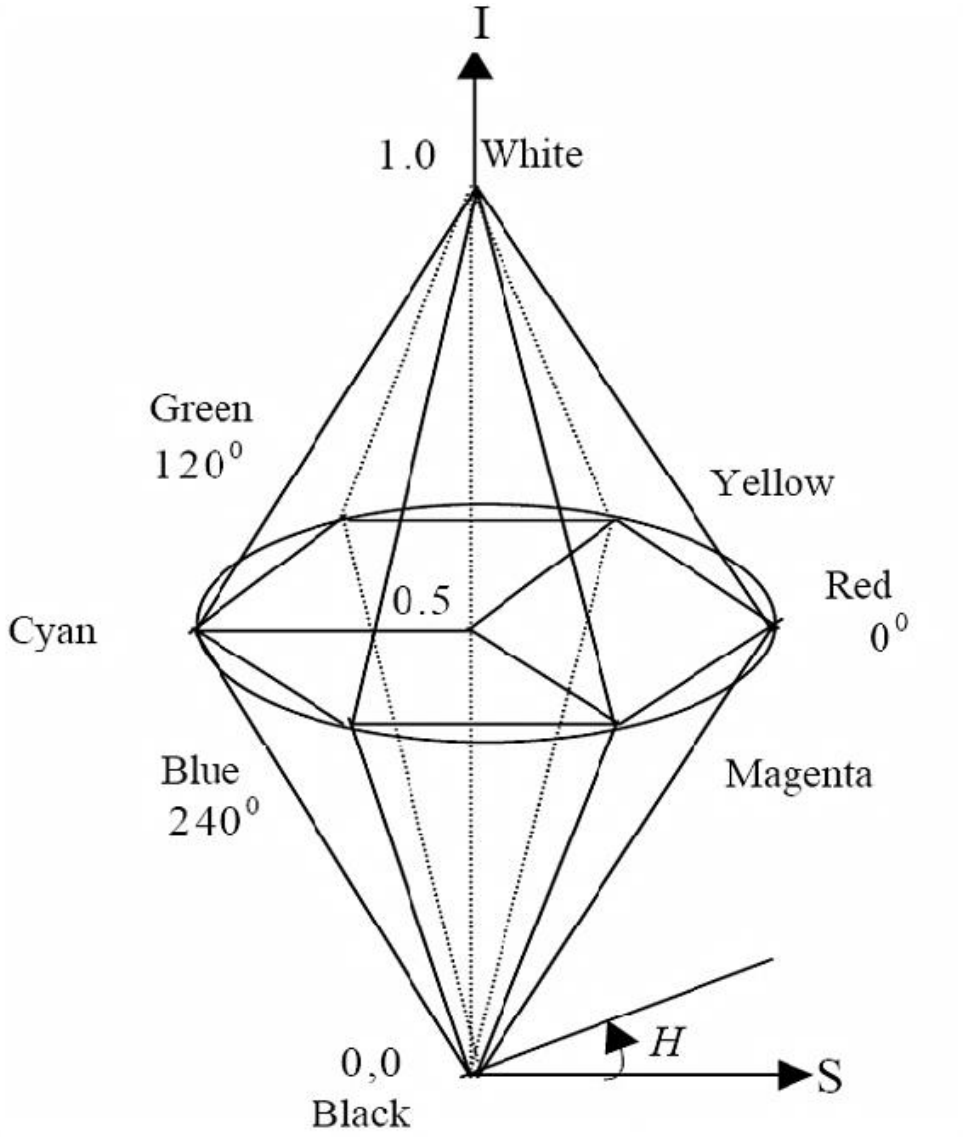
Disadvantage of RGB model

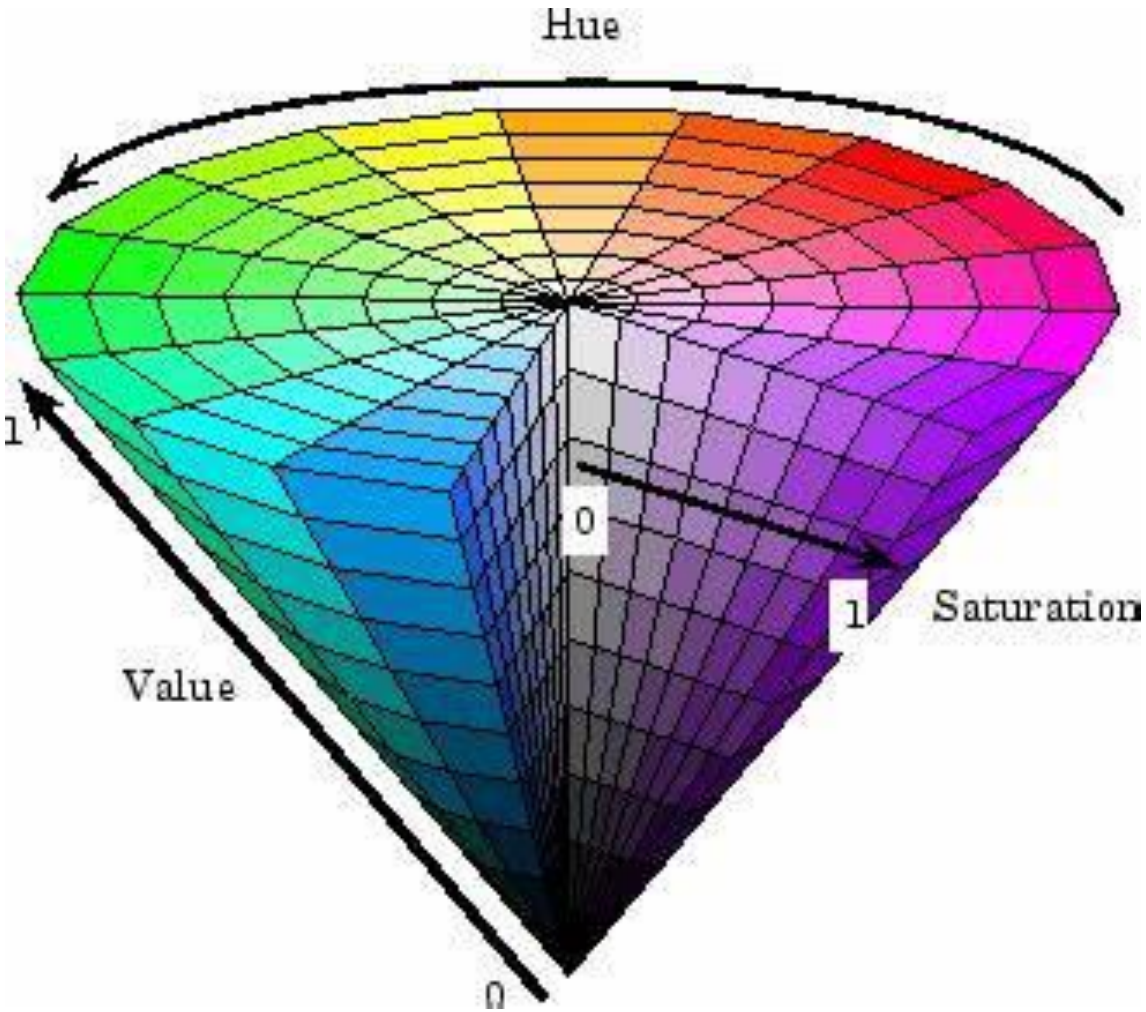
- Difficult for human description of color (e.g., humans don't describe color as RGB percentages)
- Highly redundant and correlated (e.g., all channels hold luminance information, reduces coding efficiency)

HSI Color Model

Describes pure/dominate color perceived by observer (e.g., pure yellow, orange, red)	Amount of white light mixed with hue	High saturation = high purity = little white light mixed with hue	Brightness
Hue	Saturation (Purity of color)		Intensity

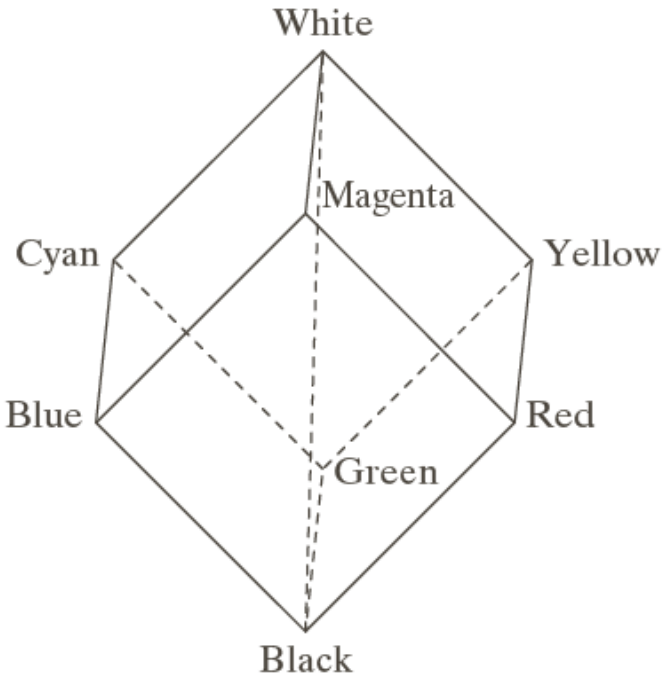
Useful for human color interpretation

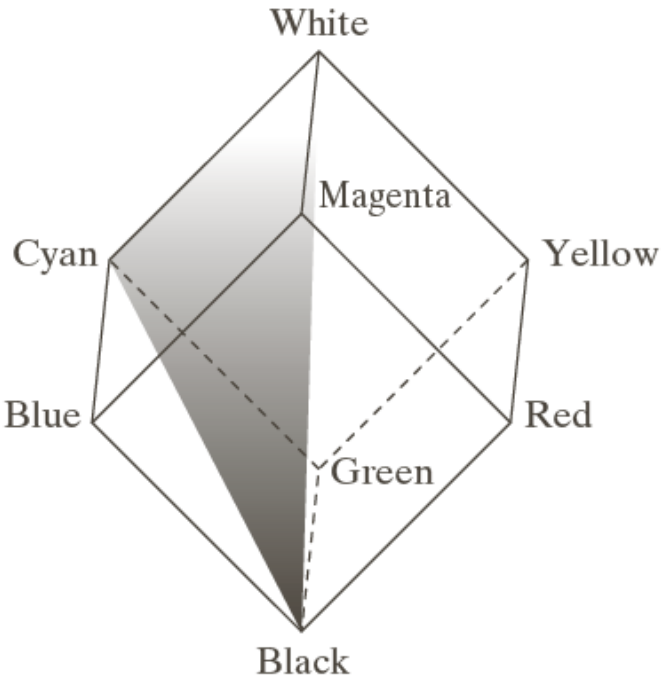

I
1.0
White
Green
120°
Yellow
0.5
Red
0°
Cyan
Blue
240°
Magenta
H
0,0
Black
S


Hue
1
0
1
Saturation
Value
0

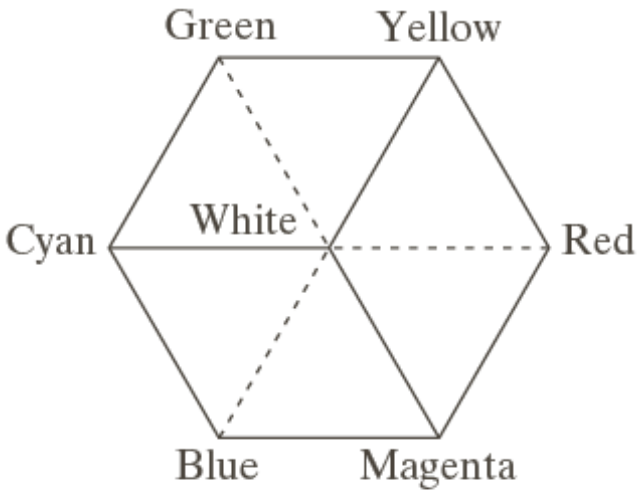
Relationship between RGB and HSI

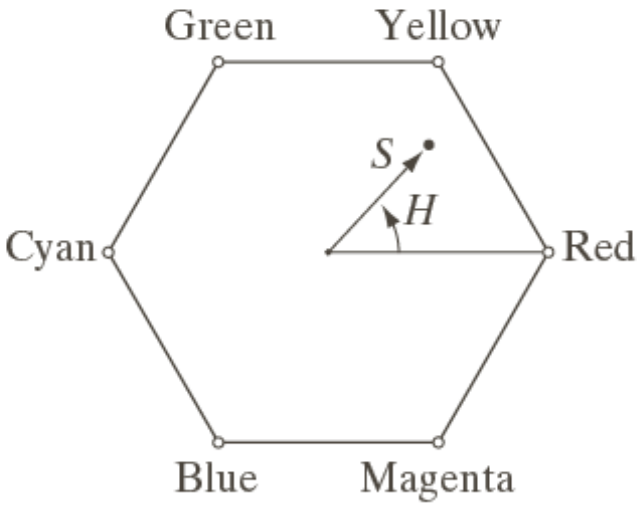
- **Hue:** all colors on plane defined by white, black, and a pure color corner point have same hue
- **Saturation:** distance from associated pure color
- **Intensity:** projection to gray scale line

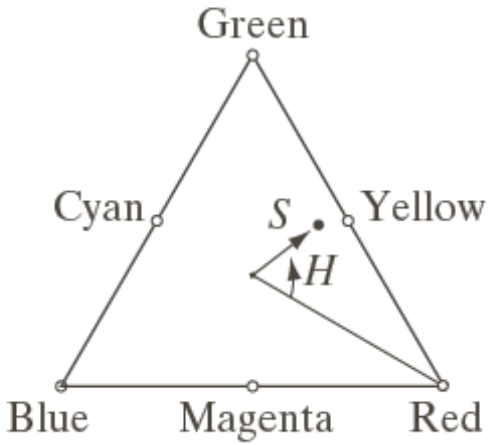


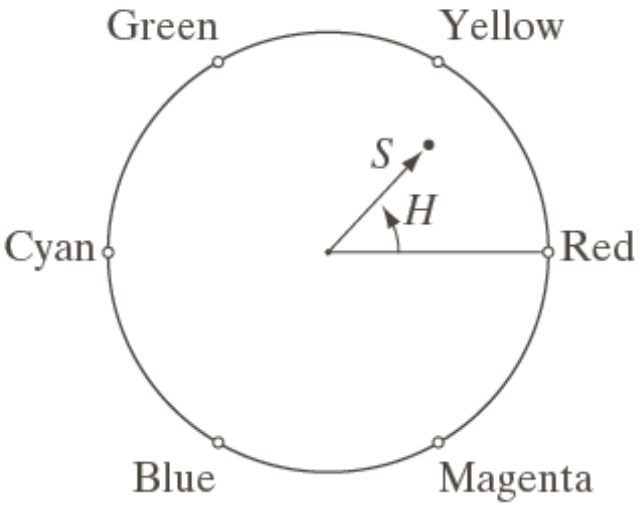


Relationship between RGB and HSI

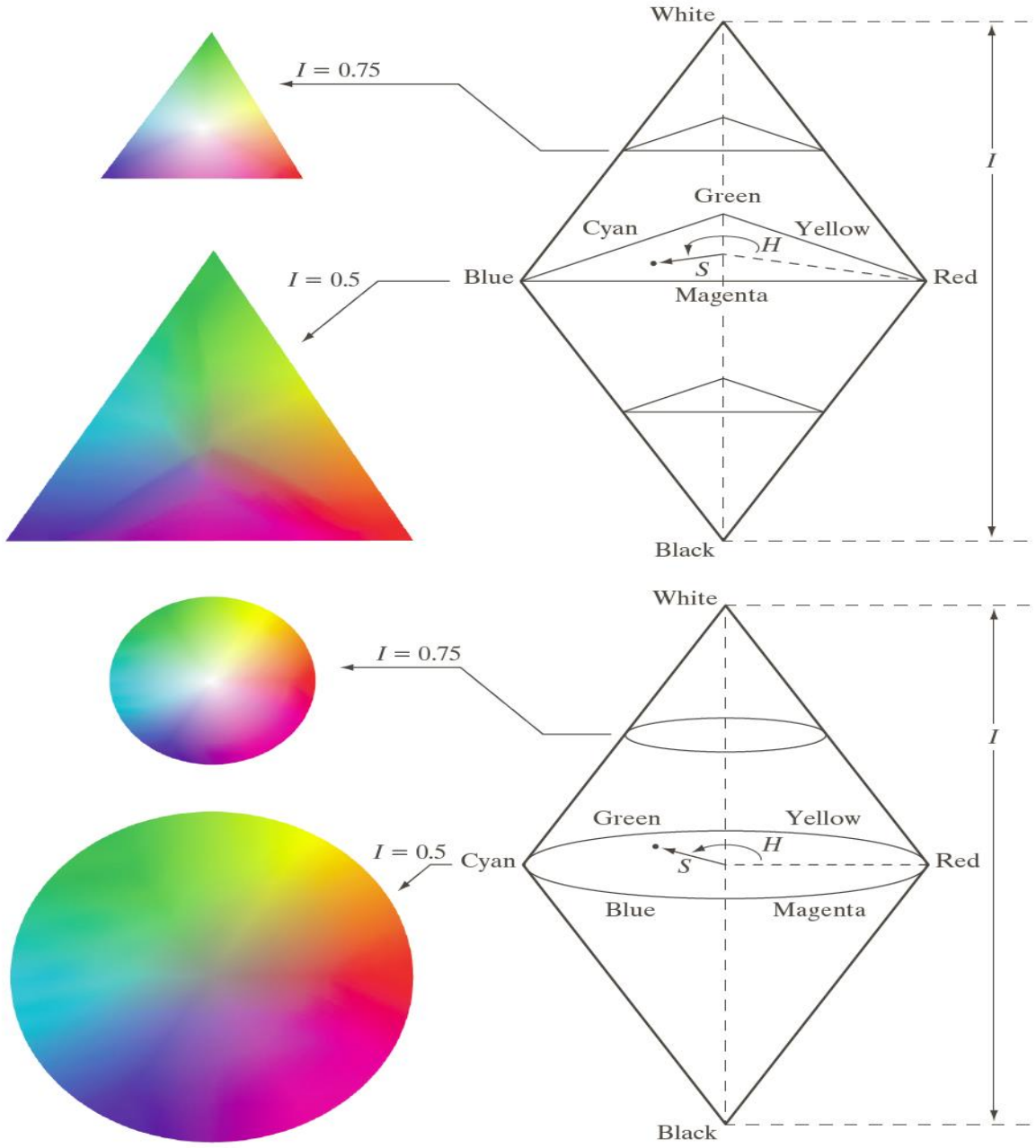








HSI Color Model Visualization



Converting colors from RGB to HSI

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360 - \theta & \text{if } B > G \end{cases}$$

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}} \right\}$$

$$S = 1 - \frac{3}{R+G+B}[\min(R,G,B)]$$

$$I = \frac{1}{3}\left[R+G+B\right]$$

Converting colors from HSI to RGB

- When H is in RG Sector

$$(0^0 \le H \le 120^0)$$

$$B = I(1-S)$$

$$R = I\left[1+\frac{S\cos H}{\cos(60^0 - H)}\right]$$

$$G = 3I - (R+B)$$

Converting colors from HSI to RGB

- When H is in GB Sector $(120^0 \le H \le 240^0)$

$$H = H - 120^0$$

$$R = I(1 - S)$$

$$G = I\left[1 + \frac{S\cos H}{\cos(60^0 - H)}\right]$$

$$B = 3I - (R + G)$$

Converting colors from HSI to RGB

- When H is in RG Sector $(240^0 \le H \le 360^0)$

$$H = H - 240^0$$

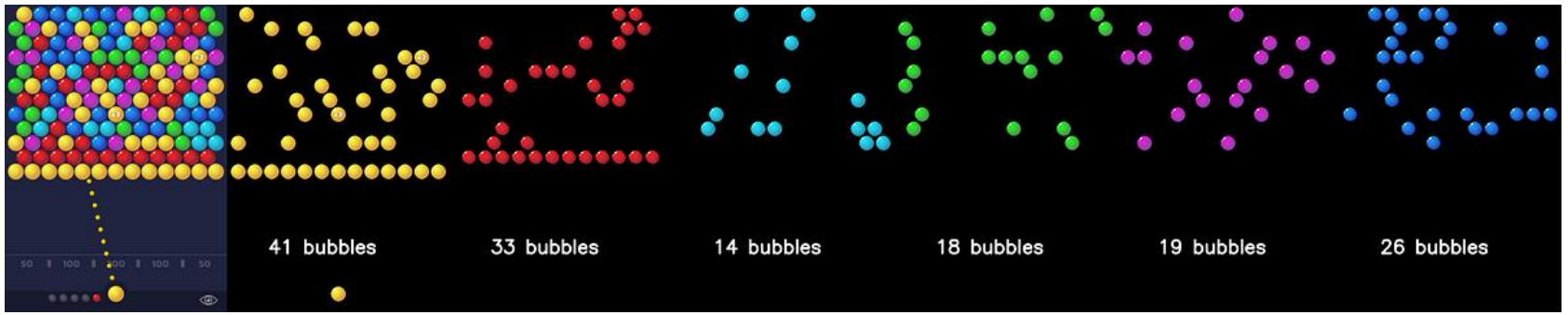
$$G = I(1 - S)$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60^0 - H)}\right]$$

$$R = 3I - (G + B)$$

Color Thresholding & Clustering (K-means)

- Set color ranges to extract regions (thresholding).
- Use clustering to group similar colors.
- Common in object detection.



Region-based and Edge-based Color Segmentation

- Region growing and merging in color space.
- Edge detection with color gradients.
- Combines spatial and chromatic cues.

Object Tracking in Videos

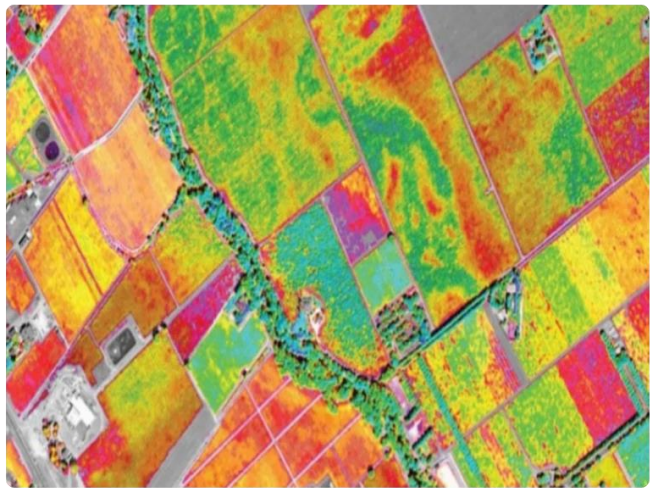
Track objects using color histograms.

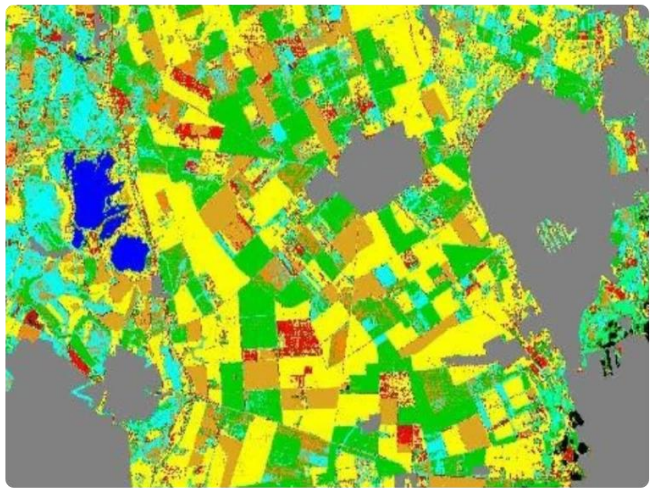
Color constancy and lighting variation challenges.

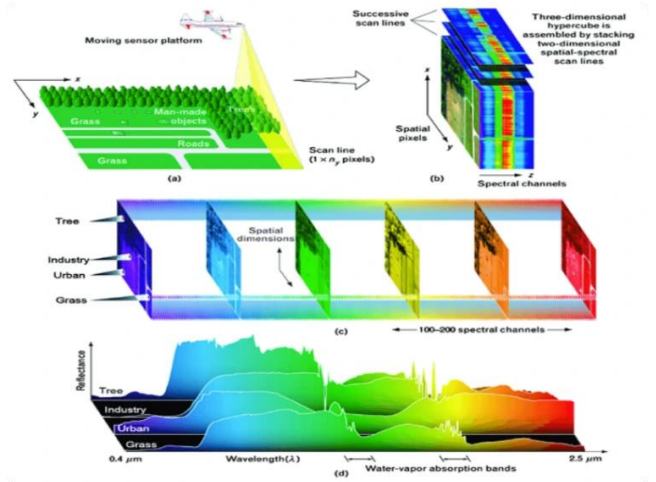
Used in surveillance, AR.

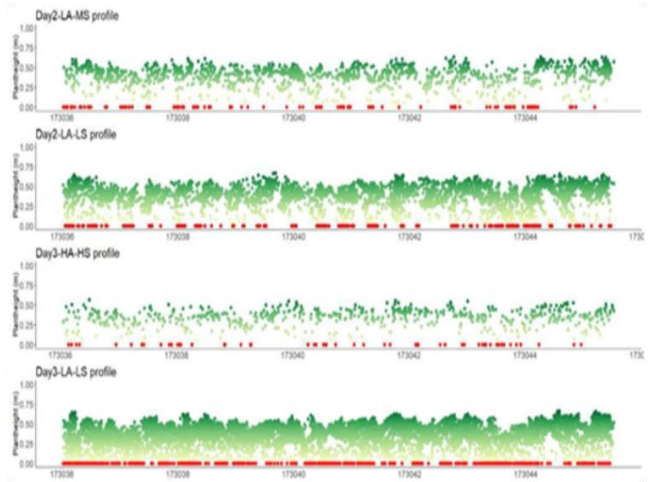
Remote Sensing and Agriculture

- Vegetation indices (NDVI) use multispectral color bands.
- Used in crop monitoring, land use analysis.
- Color composites enhance analysis.

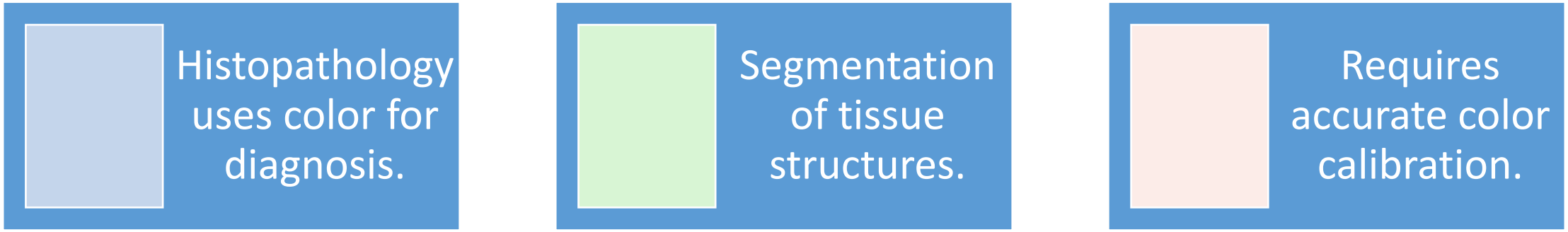








Color Analysis in Medical Imaging



Feature	**Virtual Reality (VR)**	**Augmented Reality (AR)**
Definition	Fully immersive digital environment	Overlay of digital content on the real world
User Experience	User is isolated from real world, placed inside a virtual world	User interacts with real world enhanced by virtual elements
Devices	VR headsets (e.g., Oculus Rift, HTC Vive, PS VR)	Smartphones, AR glasses (e.g., HoloLens, Magic Leap), tablets
Environment	Completely computer-generated	Real-world environment with digital overlays
Interaction	Uses controllers, hand tracking, sensors	Uses camera, GPS, motion sensors to align digital data
Applications	Gaming, training simulators, therapy, education, virtual tours	Retail (AR fitting), navigation, real-time translation, gaming
Examples	Beat Saber, Flight Simulators, Google Earth VR	Pokémon Go, IKEA Place app, Snapchat filters
Immersion Level	High (blocks out physical world)	Medium (enhances real world)
Development Complexity	Higher (complex 3D environments)	Moderate (real-world tracking + overlays)
Latency/Responsiveness	Needs low-latenc	

AUGMENTED REALITY
VIRTUAL REALITY